Prepublished copy

Nature Environment & Pollution Technology

This is a peer-reviewed prepublished version of the paper to be published in Vol. 25, No. 4, December 2026 issue

Pollution Emissions from the Kaeng Sian Landfill: Assessment and Sustainable Waste Management for Kanchanaburi Province, Thailand

Sasitorn Hasin[1], Saowaluck Haosagul[2] and Apichaya Sawasdee[1]†

[1]Program in Innovation of Environmental Management, College of Innovative Management, Valaya Alongkorn Rajabhat University Under the Royal Patronage, Pathumthani 13180, Thailand
[2]Division of Future Mobility Policy, Office of National Higher Education Science Research and Innovation Policy Council, Bangkok 10330 Thailand
ORCID: https://orcid.org/0000-0001-5947-5797
†Corresponding author: Apichaya Sawasdee; apichaya.s@vru.ac.th

Key Words	Kaeng Sian landfill, Leachate, Municipal solid waste, Waste management, Pollution emissions
DOI	https://doi.org/10.46488/NEPT.2026.v25i04.D1919 (DOI will be active only after the final publication of the paper)
Citation for the Paper	Hasin, S., Haosagul, S. and Sawasdee, A., 2026. Pollution emissions from the Kaeng Sian landfill: Assessment and sustainable waste management for Kanchanaburi Province, Thailand, *Nature Environment and Pollution Technology*, 25(4), D1919. https://doi.org/10.46488/NEPT.2026.v25i04.D1919

Abstract

This study aims to assess the types and quantities of pollution generated from landfills and to propose waste management approaches consistent with sustainable development and the circular economy. The research presents the composition of solid waste and the GHG emissions estimated at the landfill site. The highest component of municipal solid waste (MSW) is plastic, at 30.39%, followed by food waste at 27.75%. The lowest MSW composition is hazardous waste at 0.23%. The total volume of solid waste in the landfill area is 736,492.12 ± 8,326.36 m^3. The GHG emissions from the landfill site were estimated as CH_4, totaling 17,631.44 tCO_2 eq. The suggested waste management strategy was developed based on the results and includes the following measures: 1) Emergency Measures, 2) Intermediate Actions, 3) Long-term Measures, 4) Community Engagement, and 5) Technology and Data Management. Therefore, the pollution data from the landfill site presented in this study may be useful for developing strategies in Kanchanaburi province to mitigate climate change. Finally, this research can contribute to addressing municipal solid waste management (SDG 12) and climate action (SDG 13), which aim to: support climate change adaptation, integrate climate change measures into national policies, and raise awareness about climate change.

1. INTRODUCTION

Solid waste management is a key environmental issue in Thailand, particularly in the context of climate change and community environmental quality. Landfill sites in developing countries are expected to grow, which will increase GHG emissions (IPCC 2007; Menikpura & Sang-Ann 2014). Landfilling, the primary method used in many areas, remains a major source of multiple pollutants affecting air, water, and soil due to the decomposition of organic waste. During the decomposition of organic waste, biochemical changes occur under anaerobic conditions. Bacteria break down organic matter into organic acids and greenhouse gases, including methane (CH_4) and carbon dioxide (CO_2). This process not only affects global warming but also indicates pollutant concentrations in landfills (IPCC 2019; TGO 2023).

Greenhouse gas (GHG) emissions are a critical concern in relation to rising global temperatures. This concern requires solutions to reduce GHG emissions. The Paris Agreement was a solution that aims to keep global temperature increase below 2 °C, preferably 1.5 °C (UNFCCC 2016). Currently, the world is already directly affected by global warming and greenhouse gas emissions. CO_2 emissions' effects will worsen in the future (Iglina et al. 2022), including increasing global temperatures (Xu et al. 2021), melting glaciers (Aichele & Felbermayr 2012), and increased flood risk (Zheng et al. 2021).

The waste sector is a significant source of GHG emissions. Approximately 5% of the world's GHG emissions come from the waste sector (Kristanto et al. 2020). In Thailand, the waste sector in 2018 emitted 16,703.68 $GgCO_2$ eq, with emissions mainly originating from solid waste disposal, accounting for 8,774.67 $GgCO_2$ eq (52.53%) (Climate Change Management & Coordination Division 2022). Moreover, ineffective waste management can result in harmful health impacts, increased air, soil, and water pollution, greenhouse gas (GHG), toxic emissions, and the loss of valuable materials and services (Kamaruddin et al. 2022).

Pollution from landfill sites, such as water pollution, odors, and insect proliferation, is a major concern for nearby communities and adversely affects living conditions (Piboon et al. 2022; Muchangos & Tokai 2020). Major greenhouse gases (GHGs) emitted from landfill sites include methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O). In particular, the high rate of methane gas released into the atmosphere from ineffective management of municipal solid waste at landfill sites further exacerbates emissions (Fikri et al. 2024).

The accumulation of methane gas in landfills without proper ventilation systems can cause high pressure, leading to leaks or explosions. In addition, methane gas is often contaminated with volatile organic compounds (VOCs) and hydrogen sulfide (H_2S), of which are odor-causing and toxic at high concentrations. Boongla et al. (2025) reported that landfills in central Thailand have an average CH_4 concentration of 40–60% of the total gas, and VOC emissions are associated with the proportion of organic waste, particularly food and agricultural waste (TGO 2023).

In addition to gas release, the decomposition of organic waste directly affects leachate generation, as rainwater seeps through the waste layer and dissolves organic matter, heavy metals, and other chemicals (Kiddee et al. 2014). Increased methane and leachate levels often occur simultaneously in ponds with a high proportion of organic waste, suggesting a link between greenhouse gas generation and landfill pollution. That is the decomposition of waste that produces CH_4 also facilitates the dissolution of organic acids and heavy metals, which are pollutants that further spread into water and soil systems (Parvin & Tareq 2021). Wisitthammasri et al. (2024) also found that decomposition of organic waste at high temperatures in a landfill can accelerate the breakdown of plastic materials into microplastics, which are commonly found in leachate and tend to migrate into surface water sources or groundwater. Therefore, greenhouse gas emissions and landfill pollution are systematically related, with biochemical processes within landfills being the source of both greenhouse gases (CH_4, CO_2) and water and soil pollutants (leachate, PFAS, microplastics).

Kanchanaburi is a province with significant tourism, agriculture, and community activities, generating substantial municipal solid waste. The Khao Thong area, Kaeng Sian Subdistrict, Mueang District, Kanchanaburi Province, has landfill sites for waste dumping covering 53 rai (approximately 84,800 m²) (Sawasdee et al. 2022). Generally, the municipal solid waste is obtained from Kanchanaburi and other provinces. As a result, MSW in Kanchanaburi Province has increased, leading to higher GHG emissions. It is a significant phenomenon that affects people and the environment. Therefore, this study focuses on assessing the levels and patterns of pollution in the Kaeng Sian landfill in Mueang District, Kanchanaburi Province, including greenhouse gas emissions and leachate, as well as the impacts on the surrounding environment.

This study aims to assess the types and quantities of pollution generated from landfills and to propose waste management approaches aligned with the principles of sustainable development and the circular economy. However, if municipal solid waste is managed through an appropriate combination of policies, waste management can be effective.

2. MATERIALS AND METHODS

2.1 Data collection

The data for this study were collected from a landfill site located in Kaeng Sian Subdistrict of Mueang District, Kanchanaburi Province (Fig. 1). We utilized both field surveys and the application of digital technology to obtain accurate and comprehensive data, which can efficiently be used to assess waste volume and type.

Fig. 1: Landfill site at Kaeng Sian Subdistrict, Mueang District, Kanchanaburi Province.

The data collection process included the following methods: classifying MSW using the quartering method; surveying the entire landfill site; using Unmanned Aerial Vehicles (UAVs); and analyzing satellite imagery to evaluate the total amount of MSW in the landfill site. All data were used to assess the pollution generated by the landfill, informing the development of waste management strategies aligned with the principles of sustainable development and the circular economy.

2.2 Quartering method

Municipal solid waste consists of various types, including food waste, plastic, wood, garden waste, paper, glass, rubber, hazardous waste, and electronic waste. To ensure that the sample represents the overall composition of municipal solid waste, it must be sampled systematically. The quartering method is shown in Fig. 2.

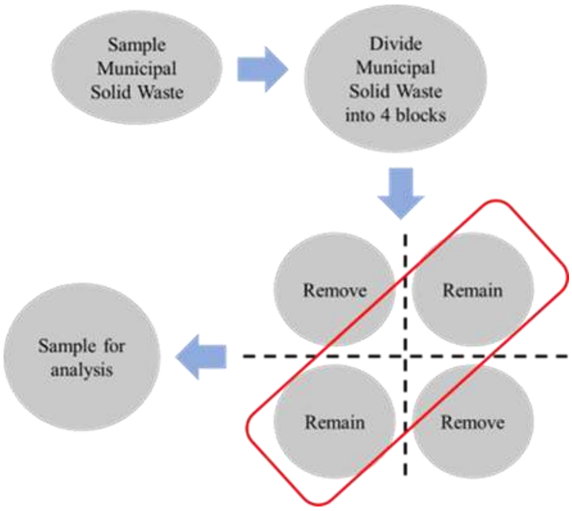


Fig. 2**:** Quartering method for municipal solid waste analysis in a landfill site.

To begin, a random sample of MSW was taken from the waste heap area. The MSW was mixed thoroughly until it was homogenized, and then divided it into four equal parts. This process was repeated until at least 100 kg of sample was obtained (Rojas-Valencia & Nájera-Aguilar 2012; PCD 2022).

2.3 UAV (Unmanned Aerial Vehicle) and satellite imagery

This study utilized an Unmanned Aerial Vehicle (UAV) survey (Fig. 3) combined with satellite imagery analysis to assess the volume and spatial distribution of solid waste at the Kaeng Sian landfill in Kanchanaburi. Drones equipped with high-resolution RGB cameras were used to survey the landfill area, producing orthophotos and digital surface models (DSMs) with a spatial resolution of approximately 2–5 cm per pixel.

Fig. 3: Survey of the entire landfill site using a UAV (Unmanned Aerial Vehicle) in Kaeng Sian, Kanchanaburi.

The surveys were conducted at an altitude of approximately 100–120 m above ground level along a predefined grid path to cover the entire area and achieve at least 80% image overlap.

2.4 Concentration of CH_4 measurement in the landfill site

Landfill gas (LFG), which results from the anaerobic degradation of MSW in a landfill site, consists of roughly 60% methane (CH_4) and 40% carbon dioxide (CO_2) (ATSDR 2008). Landfilling is the third-largest source of uncontrolled anthropogenic CH_4 emissions. Measuring methane gas in landfill sites is a crucial component in assessing greenhouse gas emissions, as methane is the primary gas produced by the anaerobic decomposition of organic matter and has a high global warming potential. Measuring methane concentration enables estimation of greenhouse gas emissions in terms of carbon dioxide equivalents, providing essential data for planning emission reductions and sustainable landfill management. However, a high amount of methane gas is generated at the landfill site in Kaeng Sian, Kanchanaburi Province. Therefore, CH_4 was measured using a portable methane gas analyzer (Fig. 4) (SKY 2000-CH_4; ATEX-, CE-, and ISO 9001-certified).

Fig. 4: SKY 2000-CH_4; Portable CH_4 methane gas analyzer with ATEX, CE, and ISO 9001 certification

A walking survey was conducted across the landfill site to identify areas with the highest methane gas concentrations. Holes approximately 5 meters deep were dug at 6 points, each serving as a sampling point for methane gas measurements, at the landfill site in Kaeng Sian, Kanchanaburi (Fig. 5).

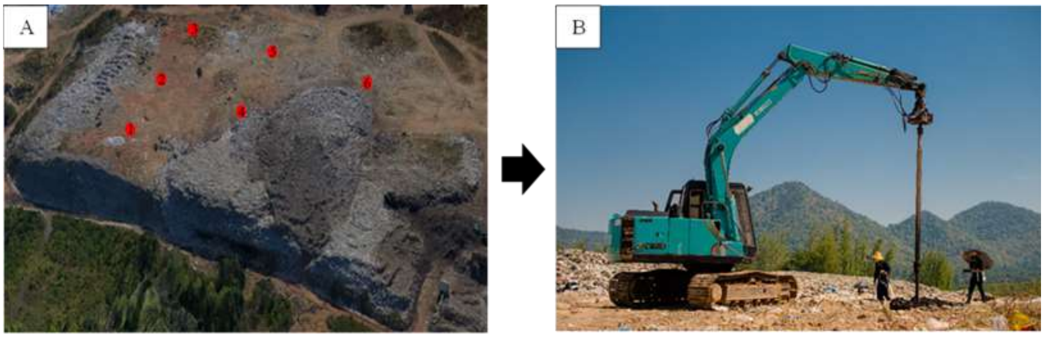


Fig. 5: A Point for methane gas measurement (Red dots) in landfill site Keang Sain, Kanchanaburi, B Dig a hole approximately 5 meters deep at each point.

2.5 Leachate analysis

Leachate samples were analyzed for chemical oxygen demand (COD) using the closed reflux method, as described in the APHA Standard Methods for the Examination of Water and Wastewater (APHA 2005). Additionally, Cadmium (Cd), Lead (Pb), Manganese (Mn), and Mercury (Hg) were measured using atomic absorption spectrometry (AAS) according to the APHA Standard Methods for the Examination of Water and Wastewater (APHA 2005).

2.6 Calculating greenhouse gas emissions

The equations for estimating CH_4 emission using the first-order decay (FOD) method from Thailand Greenhouse Gas Management Organization (Public Organization) T-VER-S-TOOL-02-02 (Calculation for Emissions from SWDS) which is modified from the IPCC Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (TGO 2023), were followed as:

$$BE_{CH4SWDS,y} = \varphi_y X \left(1 - f_y\right) (GWP_{CH4}) (1 - OX) \left(\frac{16}{12}\right) (F \times DOC_{f,y} \times MCF_y \times \sum_{x=1\cdot}^{y} \sum_j W_x \; P_j \; DOC_j \; e^{-kj(y-x)} (1 - e^{-kj}) \quad (1)$$

Where: $BE_{CH4,SWDS,y}$ represents methane emissions from the landfill site (tCO_2e), y is the year of greenhouse gas emission calculation, X is the number of years for which input data are included, φ_y is the model correction factor (Default 0.85), f_y is the proportion of methane gas that is collected from landfills and used for incineration, power generation, or other purposes (If there is no collection, the value will be equal to 0.), GWP_{CH4} is methane's global warming potential, OX is the oxidation factor (Default 0.1), 16/12 is used to convert carbon to methane, F is the proportion of methane in landfill gas (Default 0.5), $DOC_{f,y}$ is the proportion of organic carbon that can be decomposed in a year (Default 0.5), MCF_y is the methane correction factor (Default 0.4 - 1.0), W_x is the quantity of municipal solid waste, P_j is the proportion by weight of municipal solid waste type j, DOC_j is the proportion of biodegradable organic carbon (by wet weight) of organic waste type j, k_j is the decomposition rate of organic waste type j (Default 0.035-0.40) (commonly 0.15–0.43), and j is the component types of municipal solid waste.

3. RESULTS AND DISCUSSION

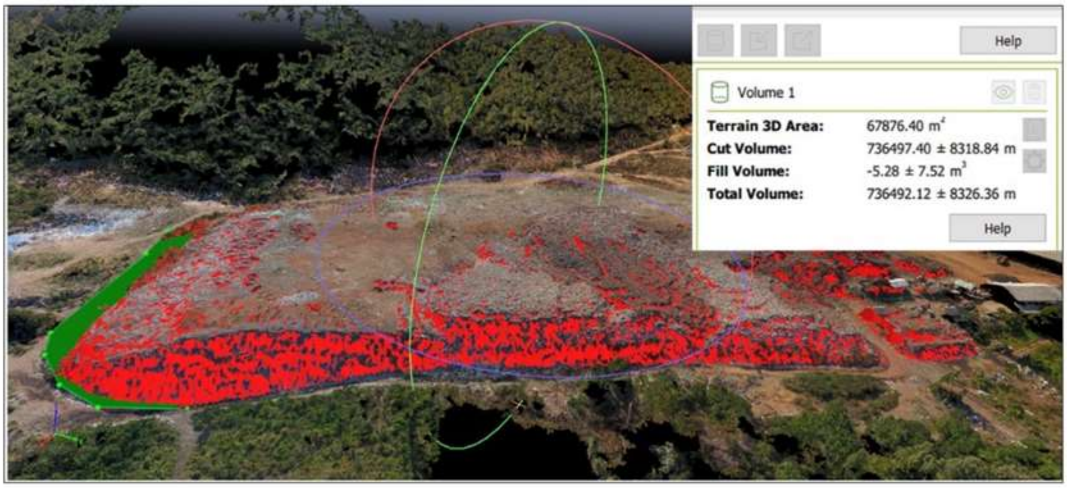
3.1 Composition of MSW

The composition of municipal solid waste (MSW) at the landfill site (Table 1) was determined using UAV (Unmanned Aerial Vehicle) imagery, satellite imagery (Fig. 6), and the quartering method. The findings reveal that plastic dominates the composition at 30.39%, followed by food waste closely at 27.75%. In contrast, hazardous waste represents only 0.23% of the total MSW. The bulk density is assumed to be 1 tonnes/m^3 (Sawasdee et al., 2022), which is used to calculate the composition of MSW.

Table 1 Composition of municipal solid waste (MSW) in the landfill site

No.	Composition of MSW	Results (%)	Result (ton)
1	Food waste	27.75	204,376.56
2	Garden waste	5.59	41,169.91
3	Wood	2.01	14,803.49
4	Paper	8.39	61,791.69
5	Plastic	30.39	223,819.96
6	Metal	0.69	5,081.80
7	Glass	1.85	13,625.10
8	Textile	7.67	56,488.95
9	Infectious waste	4.21	31,006.32
10	Rubber and leather	0.91	6,702.08
11	Hazardous waste	0.23	1,693.93
12	Electronic waste	0.54	3,977.06
13	Other waste	9.77	71,955.28
	Total	**100**	**736,492.12**

Although plastic waste constitutes the largest share of MSW, we must shift our focus to managing food waste, garden waste, wood, paper, and textiles as a priority. These materials not only pose a significant environmental challenge but also contribute substantially to greenhouse gas (GHG) emissions from landfill sites. Addressing these waste categories first can lead to more effective waste management practices and a significant reduction in harmful emissions.



Terrain 3D Area: 67876.40 m^2
Cut Volume: 736497.40 ± 8318.84 m
Fill Volume: -5.28 ± 7.52 m^3
Total Volume: 736492.12 ± 8326.36 m

Fig. 6: MSW volume in the landfill site at Kaeng Sian, Kanchanaburi.

The amount of waste is continuously increasing, as data collected on the number and size of garbage trucks dumping waste at the landfill shows a steady rise (Sawasdee et al., 2022). Therefore, proper waste management is necessary to reduce landfill contamination and prevent the spread of diseases.

Explanation of the results of the three-dimensional model analysis:

The results of aerial photograph processing using a UAV to create a 3D model of the landfill area provided the following important parameters:

1. Three-dimensional terrain surface area

The three-dimensional terrain surface area is the total surface area of the landfill, derived from a Digital Surface Model (DSM) generated from UAV imagery. This area includes surface roughness features such as waste mounds, slopes, and pond edges. The area value of 67,865.40 m^2 represents the actual surveyed area within the scope of the volume calculation, which is used as a database for spatial analysis and landfill site management planning.

2. The cut-off volume

The cut-off volume refers to the volume of material (e.g., waste, litter, and topsoil) that is above the reference surface and must be removed ("cut off") if the area is to be leveled with the base. For a landfill, this data reflects the total accumulated waste volume above the landfill's reference surface, which is 736,497.40 ± 8,318.84 m^2, accounting for image resolution (Ground Sampling Distance) and elevation model corrections.

3. Fill Volume

Fill volume is the amount of material required to fill in areas that are lower than the base of the terrain to make the ground level even. The fill volume is -5.28 ± 7.52 m^3. A negative fill volume indicates that the majority of the landfill area is raised above base level, with only a few depressions; thus, there is no need for additional fill.

4. Total Volume

The total volume is 736,492.12 ± 8,326.36 m^3, which is the net sum of the cut and fill calculations, showing the actual accumulated waste volume in the landfill at the time of the survey. This value can be used to analyze waste management potential and assess methane gas (CH_4) emissions in the next step.

The analysis results indicate that the Kaeng Sian landfill has accumulated waste volumes exceeding 736,000 m^3, indicating that it is nearing capacity. Therefore, effective waste management plans are necessary, such as separating and reusing recyclable waste, modifying the landfill surface to reduce leachate generation, and installing systems for continuous monitoring of subsidence and greenhouse gas emissions.

Fig. 7: Daily (A, B) and Old (C, D) municipal solid waste at the landfill site

The landfill site's waste volume and organic waste content resulted in high GHG emissions. The waste present included both old waste that had been accumulating for more than 10 years and new waste deposited daily by garbage trucks. The average amount of waste dumped in the area is 216 tons per day (Sawasdee et al., 2022). Therefore, measures should be taken to manage both old and new waste (Fig. 7) transported to the site to reduce greenhouse gas emissions from landfills, reduce residual waste, and improve the quality of life for residents in the surrounding areas.

3.2 CH_4 Emission from the landfill site

The concentration of methane gas at the landfill site was detected at 40.52%±0.11 – 50.47%±0.04 (Fig. 8). Methane gas is released into the air during the decomposition of organic waste, such as food, wood, or paper. The proportion of organic waste in the landfill site was 43.74%. However, methane gas can be a significant local source of alternative energy. Moreover, the utilization of methane gas contributes to reducing GHG release and improving local air quality.

Fig. 8 Concentration of CH_4 gas at each point of the landfill site

The concentration of methane gas at the landfill site was detected at 40.52%± 0.11 – 50.47%±0.04 (Fig. 8). Methane gas is released into the air during the decomposition of organic waste, such as food, wood, or paper. The proportion of organic waste in the landfill site was 43.74%. Among the gases in the atmosphere, methane has a significant greenhouse effect. According to estimates, it is responsible for around 25% of the global temperature increase. Nearly 30% of the current global temperature increase is attributed to methane (UNEP & CCAC 2021).

When MSW is initially dumped in a landfill site, it goes through an aerobic decomposition phase during which minimal methane is produced. After less than a year, anaerobic conditions are created, and methanogenic bacteria start to break down the waste and produce methane. More recently buried waste (less than 10 years) produces higher levels of landfill gas emissions through bacterial decomposition, volatilization, and chemical reactions compared to older waste (over 10 years). Waste aged 0-10 years is considered relatively new, with a maximum moisture content 35% (Sawasdee et al., 2023) and contains a large amount of biodegradable organic matter, leading to methane gas production and ongoing decomposition. In waste older than 10 years, some of the easily biodegradable organic matter has already been broken down, reducing the decomposition rate. As waste ages, it continues to decompose, thereby degrading its potential and consequently reducing the rate of gas emission (Bouart & Sakunkoo, 2015).

The GHG emissions from the landfill site were primarily methane (CH_4), totaling 17,631.44 tCO_2 eq from First Order Decay (FOD) (Table 2). The GHG contribution comes from food waste, paper, textiles, and wood, respectively. The highest GHG contribution was obtained from food waste (15,987.09 tCO_2eq) (Table 3). Thus, food waste segregation and utilization can reduce GHG emissions.

Table 2: First Order Decay (FOD)

First Order Decay (FOD)															
j_y	**x**	**fy**	**GWP CH_4**	**OX**	**F**	**DOCf,y**	**MCFy**	**Wx**	**pj**	**DOCj**	**kj**	**16/12**	**$e^{-kj(y-x)}$**	**$(1-e^{-kj})$**	**t CO_2 eq**
0.85	10	0	28	0.1	0.5	0.5	0.8	204,376.56	27.75%	0.15	0.4	1.33	1	0.329	15,987.09
0.85	10	0	28	0.1	0.5	0.5	0.8	41,169.91	5.59%	0.2	0.17	1.33	1	0.156	410.14
.85	10	0	28	0.1	0.5	0.5	0.8	14,803.49	2.01%	0.43	0.035	1.33	1	0.034	24.85
0.85	10	0	28	0.1	0.5	0.5	0.8	61,791.69	8.39%	0.4	0.07	1.33	1	0.068	805.47
0.85	10	0	28	0.1	0.5	0.5	0.8	56,488.95	7.67%	0.24	0.07	1.33	1	0.068	403.89
								Sum							**17,631.44**

Table 3: GHG emissions from the landfill site.

Type of waste	Amount of waste	t CO_2 eq
Food waste	204,376.56	15,987.09
Garden waste	41,169.91	410.14
Wood	14,803.49	24.85
Paper	61,791.69	805.47
Textile	56,488.95	403.89
Total of GHG emissions from the landfill site		**17,631.44**

However, the landfill site problem should be addressed with appropriate remedies, and a long-term strategy should be developed accordingly (Kaushal and Sharma 2016). Therefore, the following waste management strategies are recommended to reduce GHG emissions from landfill sites: transforming the open dumping into sanitary landfills that can capture and utilize methane as an alternative energy source. Long-term strategies include CH_4 utilization from sanitary landfill, production of refuse-derived fuel (RDF) from solid waste, and electricity generation from RDF.

3.3 Leachate in the landfill area

There are three leachate ponds (Fig. 9) in the landfill area. Pond 1 had the highest COD concentration, 60,285.38 mg/L; the COD concentrations in ponds 2 and 3 were 46,436.04 mg/L and 53,768.04 mg/L, respectively (Table 4). The landfills studied in this research were over 10 years old, consistent with the review by Renou et al. (2008). In landfills older than 10 years, the leachate is often in the stabilized leachate stage, characterized by low BOD but high COD and NH_3-N levels. Furthermore, this stage of leachate contains difficult-to-degrade organic matter, reducing the efficiency of treatment by rectification ponds, particularly COD removal. Therefore, the COD values in this research indicate that rectification ponds may not be sufficient for leachate treatment. Rectification ponds should be combined with other treatment technologies, such as aeration systems, artificial wetlands, or membrane systems, to improve pollution reduction efficiency and minimize long-term environmental impact (Renou et al., 2008).

Fig. 9: Leachate ponds in the landfill area.

In terms of heavy metals, Cadmium (Cd), Lead (Pb), Manganese (Mn), and Mercury (Hg) were within the standard range of the Ministry of Natural Resources and Environment on the Establishment of Standards for Controlling the Discharge of Wastewater from Landfills in Accordance with Sanitary Principles, 2022.

Table 4: Leachate analysis in landfill area

Leachate pond	Parameters	Concentration (mg/L)
Pond 1	COD	60,285.38
	Cadmium (Cd)	<0.0020
	Lead (Pb)	0.0310
	Manganese (Mn)	1.4360
	Mercury (Hg)	0.0006
Pond 2	COD	46,436.04
	Cadmium (Cd)	<0.0020
	Lead (Pb)	0.0290
	Manganese (Mn)	1.5170
	Mercury (Hg)	0.0005
Pond 3	COD	53,768.04
	Cadmium (Cd)	<0.0020
	Lead (Pb)	0.0270
	Manganese (Mn)	1.7280
	Mercury (Hg)	0.0005

However, leachate is a major environmental problem due to waste decomposition. Leachate from landfills is contaminated with a variety of pollutants, including heavy metals and chemicals that leach from items such as batteries, light bulbs, and spray cans. The landfill site in this area lacks a proper leachate treatment system, which could lead to leachate leakage and seepage into the surrounding soil. Additionally, contamination can migrate underground, contaminating groundwater, which in turn can connect to surface water.

The impact of leachate contamination on soil affects living things and the environment. Its impacts can be classified into environmental, health, and greenhouse gas impacts (Mavakala et al. 2016) as follows:

1) Environmental impacts: Leachate can contaminate nearby groundwater and surface water sources, making them unsafe for consumption or irrigation. Moreover, it can damage aquatic ecosystems, harm fish and other organisms, and disrupt the balance of local biodiversity. The decomposition process and residual leachate also produce foul odors, which affect the surrounding environment.

2) Human Health and Communities impacts: Communities living near landfills that are not properly managed can be exposed to toxins in their water or air, leading to health problems such as skin irritation, gastrointestinal diseases, and respiratory problems. Nearby communities may experience reduced quality of life due to foul odors, insect breeding (flies, mosquitoes), and contamination of local water sources, which may also lead to social conflicts or community complaints.

3) Greenhouse Gas Emissions: Leachate contains organic matter that can be anaerobically decomposed in landfills, producing methane and carbon dioxide, two major greenhouse gases.

The suggestion of waste management strategy was concluded from the data of results follows 5 measures (Table 5): 1) Emergency Measures, 2) Intermediate Actions, 3) Long-term Measures, 4) Community Engagement, and 5) Technology and data.

Table 5: Measures to address waste management in Keang Sian landfill areas.

Measures	Details
Emergency Measures	1. Install methane gas vent pipes and arrange drainage systems around the pond. 2. Control temporary new waste acceptance and arrange for source sorting points.
Intermediate Actions	1. Wastewater treatment construction, for example: facultative lagoon, constructed wetland, Oxidation Pond, Anaerobic treatment system. 2. Improve the area into a sanitary landfill.
Long-term Measures	1. Establish a district/provincial-level integrated waste management center (Cluster System). 2. Promote Waste-to-Energy projects. 3. Develop transportation infrastructure and waste separation in the district.
Community Engagement	1. Establish a recycling waste bank. 2. Establish a waste management and environmental learning center. 3. Support waste reduction activities at the source in schools, markets, and households.
Technology and data	1. IoT Sensors are installed in the landfill area to detect CH_4, H_2S gas and temperature. 2. Use drone and GIS technology to survey waste areas and plan for recovery. 3. Create a monthly/yearly waste management database system.

The prioritization of measures is based on the severity of pollution found at landfill sites, as determined by research. Emergency measures are given the highest priority due to high methane emissions and large landfill waste accumulations, indicating urgent risks related to greenhouse gas emissions, odor, fire, and leachate contamination. Intermediate-level measures and technology-based monitoring are prioritized to improve the effectiveness of environmental control and support evidence-based landfill management. Community involvement and long-term policy measures are crucial for sustainable waste management and align with Sustainable Development Goals 12 and 13. All measures aim to achieve a waste management system that is safe, effective, uses appropriate technology, reduces landfill burden, promotes a circular economy, and encourages public participation.

4. CONCLUSIONS

The research presents the composition of solid waste and the GHG emissions from the landfill site. The highest MSW composition is plastic, at 30.39%, followed by food waste, at 27.75%. The lowest of MSW composition is hazardous waste, at 0.23%, respectively. The total volume of solid waste in the landfill area is 736,492.12 ± 8,326.36 m^3. The GHG emissions from the landfill site were primarily methane (CH_4), calculated at 17,631.44 t CO_2 eq.

The proposed waste management strategies, derived from the results, include five measures: 1) Emergency Measures, 2) Intermediate Actions, 3) Long-term Measures, 4) Community Engagement, and 5) Technology and data. However, if municipal solid waste is managed through an appropriate combination of policies, waste management can be effective..

Moreover, GHG emission data from this study may be useful for developing strategies in Kanchanaburi province to mitigate climate change. Therefore, the findings of this study can support climate change mitigation planning at the provincial level. Finally, this research can contribute to addressing municipal solid waste management (SDG 12) and climate action (SDG 13), which aim to support climate change adaptation, integrate climate change measures into national policies, and raise awareness of climate change.

5. ACKNOWLEDGEMENTS

We would like to acknowledge financial support from Keang Sian Power Co., Ltd. Moreover, the authors would like to thank Valaya Alongkorn Rajabhat University under the Royal Patronage for technical support.

6. REFERENCES

1. Aichele, R. and Felbermayr, G., 2012. Kyoto and the carbon footprint of nations. *Journal of Environmental Economics and Management*, 63(3), pp.336–354. https://doi.org/10.1016/j.jeem.2011.10.005
2. APHA, 2005. *Standard methods for the examination of water and wastewater*. 25th ed. Washington, DC: American Public Health Association.
3. ATSDR, 2008. Chapter 2: Landfill gas basics. In: *Landfill gas primer – an overview for environmental health professionals*. Available at: https://www.atsdr.cdc.gov/HAC/landfill/PDFs/Landfill_2001_ch2mod.pdf (Accessed: 7 August 2023).
4. Boongla, Y., Changphuek, S. and Saehuang, A., 2025. Estimation of characteristics, methane generation and sustainability of municipal landfill waste in an urban city, Thailand. *Recycling*, 10(1), p.15. https://doi.org/10.3390/recycling10010015
5. Bouart, O., and Sakunkoo, P., 2015. Determination of Methane Potential by Default Method, First Order Decay Method and LandGem from a Controlled Dump Site: A Case Study of Nakhonphanom Municipality in Nakhonphanom Province. *KKU Research Journal (GRADUATE STUDIES),* 15(1), pp. 93-104. https://ph02.tci-thaijo.org/index.php/gskku/article/view/47160
6. Climate Change Management and Coordination Division, 2022. *Long-term low greenhouse gas emission development strategy*. Ministry of Natural Resources and Environment. Available at: https://unfccc.int/sites/default/files/resource/Thailand%20LTLEDS%20%28Revised%20Version%29_08Nov2022.pdf (Accessed: 10 June 2025).
7. Fikri, E., Firmansyah, Y.W., Afifah, A.S. and Dewi, R.K., 2024. A projection study of gaseous pollutants formed, potential health effects and clinical codification in Piyungan landfill. *Nature Environment & Pollution Technology*, 23(1). https://doi.org/10.46488/NEPT.2024.v23i01.048

8. Iglina, T., Iglin, P. and Pashchenko, D., 2022. Industrial CO_2 capture by algae: A review and recent advances. *Sustainability*, 14(7), p.3801. https://doi.org/10.3390/su14073801
9. IPCC, 2007. *Climate change 2007: Mitigation. Contribution of Working Group III to the fourth assessment report of the Intergovernmental Panel on Climate Change*. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R. and Meyer, L.A. (eds.). Cambridge: Cambridge University Press.
10. IPCC, 2019. *2019 refinement to the 2006 IPCC guidelines for national greenhouse gas inventories*. Available at: https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/ (Accessed: 5 April 2025).
11. Kamaruddin, M.A., Norashiddin, F.A., Hanif, M.H., Shadi, A.M., Yusoff, M.S., Wang, L.K. and Wang, M.H.S., 2022. Characterization and measurement of solid waste. In: Wang, L.K., Wang, M.H.S. and Hung, Y.T. (eds.) *Solid waste engineering and management*. Handbook of Environmental Engineering, vol. 23. Cham: Springer.
12. Kaushal, A. and Sharma, M.P., 2016. Methane emission from Panki open dump site of Kanpur, India. *Procedia Environmental Sciences*, 35, pp.337–347.
13. Kiddee, P., Naidu, R., Wong, M.H., Hearn, L. and Muller, J.F., 2014. Field investigation of the quality of fresh and aged leachates from selected landfills receiving e-waste in an arid climate. *Waste Management*, 34(11), pp.2292–2304. https://doi.org/10.1016/j.wasman.2014.06.018
14. Kristanto, G.A., Pratama, M.A. and Rahmawati, D.F., 2020. Estimation of greenhouse gas emissions from solid waste management and wastewater treatment in the Nizam Zachman fishery port, Jakarta, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 423(1), p.012039. https://doi.org/10.1088/1755-1315/423/1/012039
15. Mavakala, B.K., Le Faucheur, S., Mulaji, C.K., Laffite, A., Devarajan, N., Biey, E.M., Giuliani, G., Otamonga, J.P., Kabatusuila, P., Mpiana, P.T. and Poté, J., 2016. Leachates draining from controlled municipal solid waste landfill: Detailed geochemical characterization and toxicity tests. *Waste Management*, 55, pp.238–248. https://doi.org/10.1016/j.wasman.2016.04.028
16. Menikpura, N. and Sang-Arun, J., 2013. *User manual estimation tool for greenhouse gas (GHG) emissions from municipal solid waste (MSW) management in a life cycle perspective*. Institute for Global Environmental Strategies.
17. Muchangos, L.S. and Tokai, A., 2020. Greenhouse gas emission analysis of upgrading from an open dump to a semi-aerobic landfill in Mozambique – the case of Hulene dumpsite. *Scientific African*, 10, p.e00638. https://doi.org/10.1016/j.sciaf.2020.e00638
18. Parvin, F. and Tareq, S.M., 2021. Impact of landfill leachate contamination on surface and groundwater: A review. *Applied Water Science*, 11(6), p.108. https://doi.org/10.1007/s13201-021-01431-3
19. PCD, 2022. *The waste composition study in 2021*. Available at: https://www.pcd.go.th/wp-content/uploads/2022/08/pcdnew-2022-08-09_08-58-28_103322.pdf (Accessed: 10 June 2025).
20. Piboon, P., Damrongsak, D., Wongsapai, W. and Yodchumpoo, P., 2022. Greenhouse gas emission reduction in refuse-derived fuel production from municipal solid waste. *AIP Conference Proceedings*, 2681(1), pp.020031-1–020031-7. https://doi.org/10.1063/5.0115998
21. Rojas-Valencia, M.N. and Nájera-Aguilar, H., 2012. Analysis of the generation of household solid wastes, household hazardous wastes and sustainable alternative handling. *International Journal of Sustainable Society*, 3, pp.280–299. https://doi.org/10.1504/IJSSOC.2012.047282

22. Sawasdee, V., Hasin, S., Suknunchana, K. and Haosagul, S., 2022. *Survey of solid waste in the open dumping area and solid waste management in Kaeng Sian Subdistrict, Mueang District, Kanchanaburi Province*. Research report.
23. TGO, 2023. *T-VER-S-TOOL-02-02: Calculation for emissions from solid waste disposal sites*. Available at: https://tver.tgo.or.th/database/Uploads/Tool/46fd7947-a5cb-424a-8c28-262ac378bc15.pdf (Accessed: 5 April 2025).
24. UNEP and CCAC, 2021. *Global methane assessment: Benefits and costs of mitigating methane emissions*. Nairobi: United Nations Environment Programme.
25. UNFCCC, 2016. *The Paris Agreement*. New York: United Nations.
26. Wisitthammasri, W., Promduang, P. and Chotpantarat, S., 2024. Characterization of microplastics in soil, leachate and groundwater at a municipal landfill in Rayong Province, Thailand. *Journal of Contaminant Hydrology*, 267, p.104455. https://doi.org/10.1016/j.jconhyd.2024.104455
27. Xu, G., Li, Y., Hou, W., Wang, S. and Kong, F., 2021. Effects of substrate type on enhancing pollutant removal performance and reducing greenhouse gas emission in vertical subsurface flow constructed wetland. *Journal of Environmental Management*, 280, p.111674. https://doi.org/10.1016/j.jenvman.2020.111674
28. Zheng, J., Fan, J., Zhang, F., Guo, J., Yan, S., Zhuang, Q., Cui, N. and Guo, L., 2021. Interactive effects of mulching practice and nitrogen rate on grain yield, water productivity, fertilizer use efficiency and greenhouse gas emissions of rainfed summer maize in northwest China. *Agricultural Water Management*, 248, p.106778. https://doi.org/10.1016/j.agwat.2021.106778